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DESIGN, ERECTION AND OPERATION OF SMALL REFINERIES IN DEVELOPING COUNTRIES

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DESIGN, ERECTION AND OPERATION OF SMALL REFINERIES IN DEVELOPING COUNTRIES

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INTRODUCTION

1. The past ten years have seen a basic change in the pattern of development of refinery capacity. There is now a strong tendency to construct small refineries located in the consuming areas rather than to expand the existing large export refineries.

2. These new refineries are frequently located in developing countries, whose initial refined product demand is small and relatively simple since industrialization has not yet become a major factor in the national economy. Once the refinery has been constructed it tends to become the nucleus for industrial development in the country. Conversely, the development of the petroleum industry is stimulated by industrial growth.

3. It is essential both to the country in which a refinery is to be located and to the sponsors of the venture that a refinery of optimum size and type is built in the most suitable location, yielding in an economically viable manner the product pattern which most clearly matches the country's market demand.

4. This paper will follow the development of a typical refinery design highlighting the various problems which occur and have to be solved.

DESIGN

Product Demand Evaluation

5. The first problem encountered when considering a refinery in a new location, particularly in a newly developing country, is to determine the local product demand pattern both quantitatively and qualitatively. Demand is usually limited to the main products, viz. gasoline, kerosine, diesel and fuel oil, which can be obtained from most crude oils. However, the proportions of the various products required by the market rarely match the products that would be obtained from the simple processing of a single crude oil. This difficulty can usually be overcome by a selection of appropriate crude oils, which when supplied in the correct proportion to the refinery can closely match market requirements after simple processing. Some of the flexibility inherent in crude allocation is illustrated in Table 1.

Table 1

Flexibility in Product Output by Varying Crudes Intake

Basis: Simple Refinery	Crudes processed	
	100% Kuwait	50% Seria 50% Basrah
Yields of Products - weight %		
Motor Gasoline	18	29
Middle Distillate	23	41
Fuel Oil	59	30
	100	100

6. The same range of yield variation from a single crude could be achieved by building more complex refining and processing units, such as catalytic cracking, alkylation, isomerisation and visbreaking units, etc., which are termed secondary processing units. However, experience has shown that these secondary processing units are expensive to construct and can seldom be justified economically until some considerable time after the refinery start-up. Their construction should therefore be deferred until they are required. This results in the construction of simple refineries with few processing units and auxiliary facilities and consequently initially low capital and operating costs.

7. Nevertheless, it would be coincidental if the region for which the refinery is planned could initially absorb the entire range of products obtained from the available crude oils. Therefore, in many cases surpluses of products will occur during the initial period of operation and have to be shipped out of the area in order to find a profitable market. Also, it might be necessary to balance market demand by marginal imports of deficit products. Such movements can, of course, be very expensive and it is therefore desirable that they should be kept to a minimum.

Determination of Refinery and Processing Unit Capacity

8. Once it has been decided that a refinery is to be constructed in a certain country, the economics of the venture are studied on the basis of a number of individual refining schemes in which the supply of the crude oils or crude blends play an important part. Based on these studies the capacity of the refinery and the size and type of its processing units are determined, as warranted by the current market demand pattern of the area to be supplied by the refinery, consideration at the same time being given to the possible future extensions to meet the demands of a growing economy.

9. Governed by these considerations, the largest possible capacity for the processing units is aimed at, since it is well known that the larger the unit, the less it costs to run per unit of intake. The impact of size on the operating costs of typical simple refineries is shown in Table 2.

Table 2

Relative operating costs of various size refineries

Basis: Simple refineries without secondary processing facilities operating at full capacity

Size of refinery tons per annum	Relative costs of processing 1 barrel of crude oil
500,000	228
1,000,000	161
2,000,000	122
4,000,000	100

10. However, set against the low unit operating costs of the large refinery are the higher initial investments and, possibly even more important, the necessity of uneconomic transportation of surplus products to a point where they can be utilized. Therefore, it is important that the forecast of market demand should be

realistic in order that the refinery can be sized to meet it without having excessive idle capacity. The effect of idle refining capacity on the cost of processing one barrel of crude oil is shown in Table 3.

Table 3

The effect of idle capacity on unit operating costs

Basis: A simple refinery processing Kuwait crude oil

Percentage of refinery capacity idle	Relative costs of processing 1 barrel of crude oil
nil	100
10	109
20	118
30	129

11. As in so many phases of refinery planning, the capacity initially established for a new refinery and those of the processing units, even when the basic market requirements are known, represent a compromise and, as will be appreciated from the foregoing, are governed by economic and financial considerations closely related to the development of the country in which the refinery is to be built.

Refinery Processing Equipment

12. From experience, on the basis of initial market product requirements in developing countries, both quantitative and qualitative a more or less standard pattern for refinery development has evolved. It has been found that in the majority of cases a refinery consisting initially of a crude distilling unit and a catalytic reformer usually covers these requirements, if a low-sulphur crude is available. However, if a high-sulphur crude, such as Middle East crude, must be processed, a desulphurizing unit should be included.

13. The crude distilling unit produces gas and components for gasoline, kerosine and light and heavy fuel oils.

14. The catalytic reformer transforms the low-octane gasoline components into high-octane gasoline components. Thus even from the outset a refinery comprising a crude distiller and catalytic reformer is capable of producing an adequate number of components, which when blended in appropriate ratios will produce a comprehensive range of products closely matching initial market demands. By keeping the units initially to be installed in the refinery as simple as possible a favourable influence is obtained not only on construction costs but also on the overall operating costs.

15. However, as the economy of the country develops a demand may be created for more specialized products, for example liquid petroleum gas (LPG), bitumen, jet fuels and high-octane gasolines, and at that stage further additions to the original simple refinery scheme may become justified and a refinery development scheme as shown in figure 1 (attached) could be visualized. These additional processing facilities may consist of a hydrodesulphuriser, a catalytic cracking unit, an isomerization unit, a visbreaker, etc. It should be realized, however, that when the complexity of the refinery increases the operating cost per unit of intake will also increase, as illustrated by Table 4.

Table 4

Relative operating costs of refineries of varying complexities

Type of refinery	Relative operating costs of processing 1 barrel of crude oil
a) Crude distiller plus platformer	100
b) Same as a) plus a hydrodesulphurizer	113
c) Same as b) plus bitumen plant	116
d) Same as c) plus catalytic cracking complex	172

16. It should be emphasized here that some of these additional processing facilities, besides being expensive to operate, are also expensive to build. Therefore, the additional heavy investment should be delayed until an economic level of demand for their products is established.

Site Selection

17. Once the economic desirability of a refinery has been established and the capacity of the refinery and the size and type of processing units required determined - both for the initial project and for possible future extension - and once the amount of tankage and the area of land required have been established, a site survey is undertaken. During this survey the many factors governing the overall economics of the project and peculiar to each possible location is studied and compared. The most important of these are:

crude handling costs; product distribution costs; availability of road and rail connections; availability and costs of services such as power, cooling water, local labour, workshops, housing and the like; nature of the site; and air and water pollution.

(a) Crude handling costs

If the crude oil has to be supplied from overseas, which is usually the case, the most economical location for the refinery, from both the crude-handling and the product-distribution point of view - especially if coastal trade is involved - is normally on or close to the coast. In this case the facilities provided for handling the crude oil and products consist of jetties or buoy moorings, the latter generally being used if the water depth close to the shore is inadequate for large tankers. Usually, these facilities are planned to handle the largest size of crude carrier that can be economically justified. Here again a compromise has to be struck between possible facilities required in the future and the target of keeping the cost of the basic project within economic limits. Thus it might well be possible for the handling facilities to be planned for the maximum economic tanker size whilst other facilities, such as the receiving tankage, pumps, etc. will be staged in so far as this can be economically justified. It should be noted that if owing to certain circumstances the refinery has to be

built some distance from harbour facilities and marketing distribution installations, the economic penalty is disproportionate to the distance involved, i.e. in the case of the connecting pipelines not only their length, but also their diameter increases.

(b) Product distribution costs

Within the planned supply area of the refinery, the products can be transported from the refinery to the consuming centres by road, rail or sea or a combination of these.

The study for determining product distribution costs for the various alternative sites must take into account such factors as freight charges for the different modes of transport, the possible purchase of transport equipment, the quantities involved and the distances to centres of consumption, as well as the availability of roads, railways or waterways. Product distribution costs are a major item of expenditure and might jeopardize the overall economics of the project. Other costs for the alternative refinery sites being equal, product distribution costs have often been decisive in locating the refinery.

Normally, it is found that the most economic location is in or near a main consumption area, which usually embraces a deep-sea harbour around which economic development has already taken place.

(c) Availability of road and rail connections

If there is a marketing distribution installation in the vicinity of the refinery, which is provided with railway facilities, it is not always initially essential for the refinery to have a rail connection. The marketing installation can be connected by pipelines to the refinery and in a sense forms part of the refinery as far as tankage and rail transport are concerned, which has a beneficial effect on the overall cost of the project. Nevertheless, a rail siding alongside the refinery can be an asset during the refinery construction phase for the delivery of equipment and materials.

As soon as bulk LPG and bitumen facilities are added to the refinery, the provision of a rail connection becomes of increasing importance. As will be appreciated, good road connections are essential not only for the distribution of products by road but also for getting equipment and personnel to the site.

(d) Availability and costs of services

Where possible, the refinery, in those facets of its activities not specifically concerned with oil refining techniques, makes use to the greatest possible extent of the services which can be provided by others, provided, of course, that they can be supplied at competitive cost. The main services concerned are the supply of electricity and water, maintenance work to be performed in local engineering works, skilled labour during overhauls, housing for staff and labourers, etc., all of which should be closely studied as they may have a bearing on the siting of the refinery.

(e) Nature of the site

With the aid of topographical maps the nature of the alternative sites is examined and the amount of excavation and filling determined that will be necessary to develop the site. In addition, the suitability of the various sites for the construction of tankage and processing units is established. This is normally done by carrying out soil-boring tests to determine the type of foundations, the length of piles (if required), the type of drainage system, etc.

In theory, a refinery can be built on almost any site, for example on reclaimed or even hilly ground. However, it should be kept in mind that poor soil conditions necessitate extensive piling, foundations and drainage, which may increase the cost substantially. Similarly, a site which is irregular in shape or contour can also be expensive to develop if excessive earth-moving is involved.

The most favourable site would be a relatively flat piece of land with good soil-bearing properties, sloping gradually to a big waterway or to the sea, facilitating the drainage of the site.

(f) Air and water pollution

The elimination of nuisance from air and water pollution is a basic consideration in the siting of any refinery. The main possible sources of pollution are:

vapours released from crude oil and light product tankage; leakages from process equipment; stack gases; refinery flares; treating plant effluents; oily water effluents.

The abatement of air and water pollution has been the subject of studies for many years and it can be stated that as a result of these studies and the experience gained, pollution from the above potential sources in modern refineries is no longer a problem. With the introduction of floating roofs on crude and light product tanks the release of vapours can be almost entirely eliminated. Good housekeeping prevents the release of vapours from leakages in process equipment and the use of an efficient relief gas and liquid-disposal system can reduce air and water pollution to a negligible level.

Any obnoxious waste gases from processing units are burnt in the process furnaces and thus converted into harmless compounds, which can safely be disposed of in the atmosphere, together with the stack gases.

The use of efficient fuel burners in process furnaces and boilers and elevated stacks for adequate dispersion of combustion gases can effectively control air pollution from these sources.

Refinery flares of modern design, incorporating efficient combustion systems, are not a source of air pollution.

Treating-plant effluents in the form of spent chemicals, which used to be a problem in conventional treating plants, such as acid, caustic and doctor treaters, have now virtually been eliminated by the application of modern refinery processes, e.g. the hydrodesulphurizing process.

Efficient oil/water separators for treating refinery effluent water have been developed. It is worth noting that since the introduction of air-cooled equipment not only has the availability of large quantities of fresh or salt water for cooling purposes ceased to be the critical problem it used to be, but also the amount of possibly oil-contaminated water has been reduced considerably.

Over the years considerable strides have been made towards the virtual elimination of air and water pollution and it is possible nowadays to design refineries so that any community in the vicinity will not suffer from either air or water pollution.

Process Design and Engineering

18. Having decided where the refinery will be built, what units it will include and the capacities of the individual units, the next stage of development is the detailed process design and engineering.

19. With the construction of small refineries coming more prominently into the picture, studies were undertaken to determine how the capital and operating costs of refineries, including manpower requirements, could be reduced so that even small refineries could be made economically acceptable. As a result of these studies, in which latest technical developments in the petroleum industry are incorporated, rational or economy design concepts evolved. When applied, they satisfy these requirements without infringing on safety and operational reliability. Some of these concepts, which fall within the various cost-saving categories, entail:

- Maximizing energy savings and heat recovery by integrating processes and utilizing heat from furnace flue gases for steam generation.
- Using, where possible, air cooling instead of water cooling.
- Using very reliable equipment of high efficiency and simple design, thus obviating the need for stand-by equipment, e.g. for pumps, compressors, exchangers, electrical distribution system, etc.
- Applying internationally accepted codes to the petroleum industry instead of local ones which are often not specifically based on refinery operations.
- Having compactly built and fully integrated processing units, utilities, blending and storage facilities with one central control station and a single administration building with an annex for combined workshop and stores.
- Introducing in-line blending and product-quality measuring instruments in process units and tank farms.

20. These are just a few of the concepts leading to savings in capital and operating costs, but added together they show a substantial saving not only in these costs but also in manpower requirements.

21. In the process design stage, detailed flow diagrams for the refinery and individual processing units are prepared. Based on the available process data, the major equipment is dimensioned.

22. Engineering covers the stage during which all drawings are made according to which the refinery is to be built, and incorporates mechanical, civil and electrical designs. Furthermore, the specifications for purchasing the materials and equipment are drawn up. It is at this stage of the project that use should be made of the most modern techniques and up-to-date knowledge.

ERECTION

23. On the basis of the drawings and material and equipment specifications prepared in the design and engineering stage, the materials required to build the refinery are purchased. Where possible, materials of local origin are used. When selecting vendors, both prices and delivery times play an important role, as the time of arrival of the materials at the site has to fit in with the erection schedule.

24. Before the actual erection of the equipment can be started, a tremendous amount of civil work has to be performed, such as clearing and levelling of the site, building roads, installing underground drainage and electrical cables, preparing foundations, etc.

25. After part of the civil work has been completed and the necessary materials have arrived at the site, the erection of the equipment, tanks, pipelines, etc. can be started. Depending on location, weather conditions encountered, etc., the time required to construct a small refinery varies between 18 and 24 months, whilst that for the overall project may vary between 24 and 30 months. The skilled and unskilled labour required to perform this work, which may number a thousand men when erection is in full swing - even for a small refinery - is engaged, where possible, on the local labour market. Selected semi- and unskilled labourers usually receive training at the site under the supervision of experts engaged locally or brought in from abroad prior to being engaged on actual erection activities.

26. During the entire construction period, extensive use is usually made of the most modern erection equipment, tools and techniques.

27. As will be apparent from the foregoing, this phase in the realization of the project demands intensive planning and scheduling in order to ensure that the erection is completed within the time set and moreover is executed in the most efficient and economical manner.

OPERATION

28. Within the concept of a refinery, activities can broadly be sub-divided into those connected with the processing and handling of crude and products, with the maintenance of the refinery installations and with administration.

29. The operation of the processing units, utilities and oil movements are on a 24-hour a day basis. In order to control the process conditions of the operating units they are equipped

with automatic control instruments which are all concentrated in one central control station. These instruments enable the operator to follow changes in operating conditions as they occur and also, if necessary, to reset the operating conditions by remote control. The activities in this control centre may not only be confined to these alone but may also include others, such as blending of components into final products - in which case extensive use is made of automatic measuring and product analysing instruments - remote tank gauging, product handling, etc.

30. All these operations are usually supervised by one person who is assisted by operators and helpers to whom specific tasks and responsibilities are assigned. The number of operators required varies and is entirely governed by the complexity of the refinery.

31. Concentrating as many activities as possible in one-control centre will be beneficial not only to the efficiency of operations but also to manpower requirements and consequently to the operating cost of the refinery.

32. Besides the operators in processing units, etc., highly qualified personnel, usually with university degrees, are needed, responsible for the overall planning and supervision of operations.

33. Closely related to the operational activities are those of the laboratory. In the laboratory, equipped with special apparatus, tests peculiar to the components or products are carried out and provide a check on operations. When automatic analysers are used in the control centre, they take over some of the laboratory's duties.

34. In order to keep the refinery in an operable and safe condition between major overhauls, day-to-day maintenance has to be performed on parts of the various installations, such as on instruments, pumps, heat exchangers, pipelines, etc. This maintenance work is planned and scheduled from day to day and under normal operating conditions during the day shift maintenance will usually only have to be done. However, during a major turnaround, maintenance is often done on a 24-hour a day basis to reduce the off-stream time of the refinery.

35. For this work skilled craftsmen such as welders, pipefitters, machinists, instrument technicians, etc. are required, who usually work under the direct supervision of foremen, whilst highly qualified and experienced maintenance personnel are entrusted with the overall responsibility. The number of maintenance people permanently on the refinery's payroll is entirely determined by the extent to which local industries can supply the necessary assistance. This is of special importance for turnarounds on processing units fully integrated which have to be shut down together. If these services are available, use will be made of them to the greatest possible extent, enabling the refinery to maintain a smaller maintenance force.

36. Personnel experienced in refinery operation and maintenance are required to man a refinery. This applies particularly to the operational personnel who have daily to cope with

inflammable materials. If personnel with this specific experience cannot be found locally, it will be necessary for local works to be given an extensive training commencing well in advance of the start-up of the refinery. Key personnel might even have to be trained in other refineries abroad in order to prepare them fully for their future task. Besides the personnel directly involved in the operation and in maintenance, there is a small group which is more concerned with the future than with day-to-day problems and prepares plans for improving refinery efficiency or economics.

37. The administrative activities mainly centre around accounting, purchasing, materials and personnel, and usually do not differ significantly from those in any commercial enterprise.

38. Though conditions may differ considerably from country to country and assuming that public services can be rendered to the refinery, the total manpower requirements for a small domestic refinery will be from 100 to 200 people.

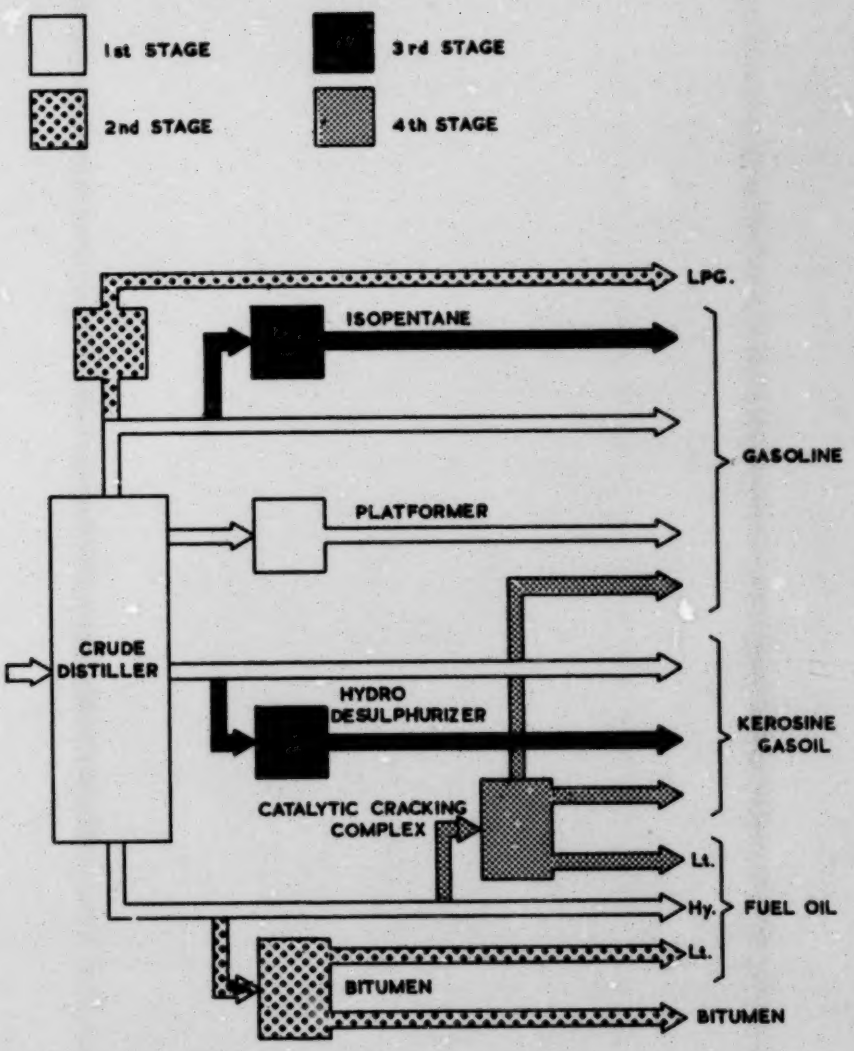
CONCLUSION

39. In the foregoing a comprehensive review has been given not only of the factors influencing the viability of a small domestic refinery in a developing country but also of the various measures which have made the small refinery economically possible.

40. As will be appreciated, it is quite impossible to express in terms of money the savings which can be obtained by each individual concept or combination, owing to the complexity of a refinery. Moreover, they may vary considerably from country to country and are further influenced by material and labour costs and the availability of public services. However, it can be stated that nowadays it is possible to build a small domestic refinery with an intake of say 20,000 barrels crude oil daily (1,000,000 metric tons per year) for 30 to 40 per cent. less than a few years ago.

FIGURE 1

DEVELOPMENT OF SMALL DOMESTIC REFINERIES BY STAGES



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